THERMAL CONTROL

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Thermal control requirements for Surveyor differ from those for all spacecraft previously flown--the nearest approaches having been in Luna IX and Ranger Block II lunar capsules, though the problems in both cases were much less sophisticated.

In addition to normal environmental conditions which all spacecraft have to withstand, Surveyor I had to survive (a) a complex terminal maneuver, which included the firing of a solid rocket motor with metal doped fuel and the firing of three liquid-fueled motors which shut off only at a 13-foot elevation above the lunar surface; (b) the lunar day, with its varying lunar surface temperatures, sun angles and shadow patterns; and (c) the lunar night insofar as possible. Surveyor I actually survived the first lunar night and, during the second lunar day, sent back many pictures together with invaluable engineering data.

Due to the unique environmental conditions imposed on Surveyor I, the approach to its temperature control design depended on the use and the temperature limits of various subsystems. Certain subsystems operated only during the transit phase of the flight, and their control on the lunar surface was not necessary. Other subsystems, which had to function on the lunar surface, could survive lunar night temperatures and still be used on the second lunar day, if they were switched off at dusk. Finally, there existed certain other subsystems which had to be kept at some temperature in the vicinity of room temperature to survive the lunar night with possible operation during that period. This led to what is termed the "open system" of temperature control, as opposed to the "closed systems" used in other spacecraft. In the open system, one indeed pays a penalty in complexity of thermal design; but one greatly reduces the power required to survive the lunar night.

Types of temperature control were (a) passive, (b) active, and (c) semi-active. Passive control (Fig. 1) exists where the radiative properties of external surfaces are controlled by paints, polished metals, or other surface treatments. In some instances, reflecting mirrors were used to direct energy onto shaded areas. For other components (Fig. 2) where the required radiative isolation could not be achieved by surface finishes or treatments, the major item was covered with an insulating blanket composed of multiple-sheet aluminized mylar.

Active control (Fig. 3) consisted of electrical heaters which were operated by either external command, thermostatic actuation, or both. This type of control was used for those units whose survival could not be achieved by passive control; and to optimize heater effectiveness, such units also had special surface finishes and insulating blankets.
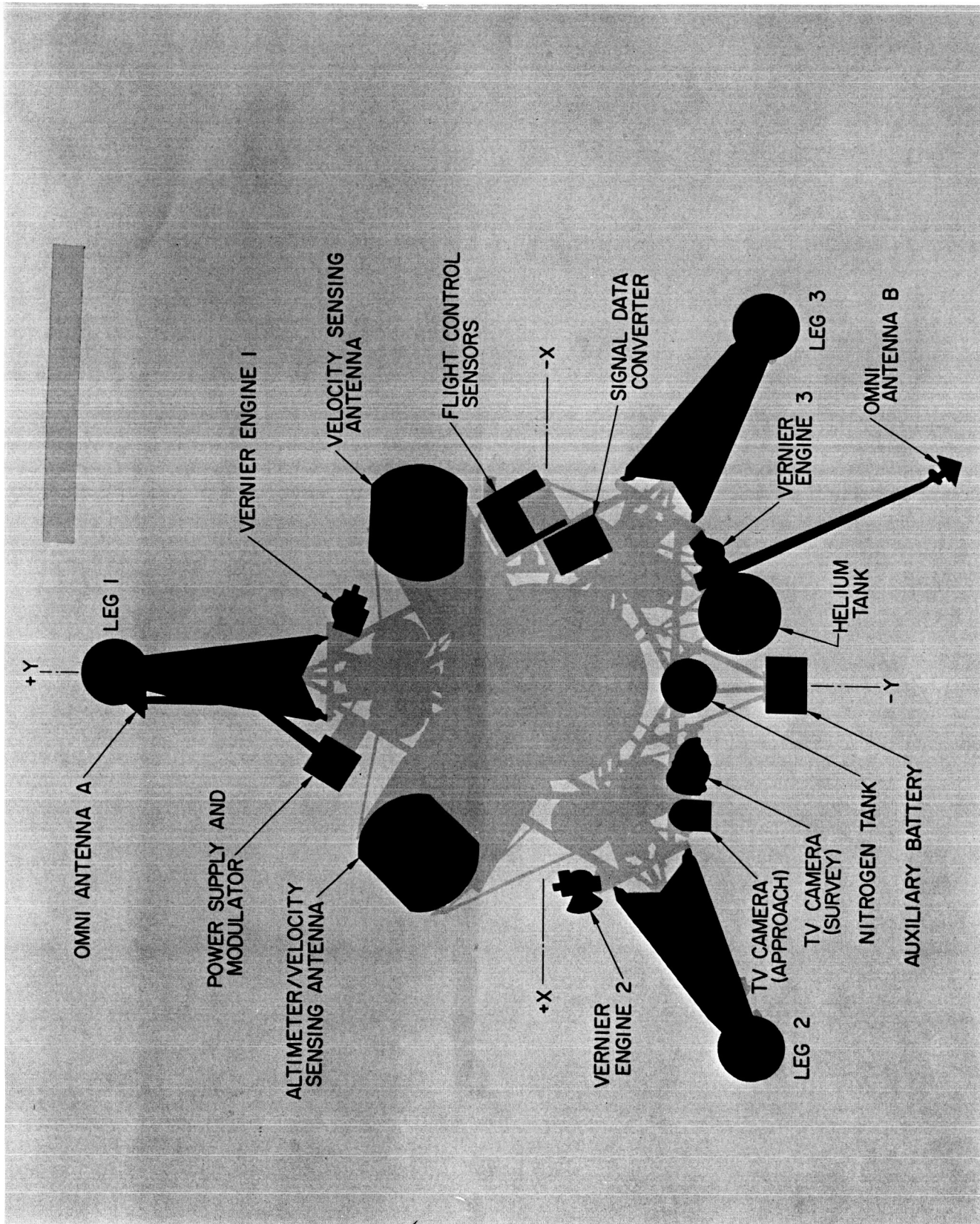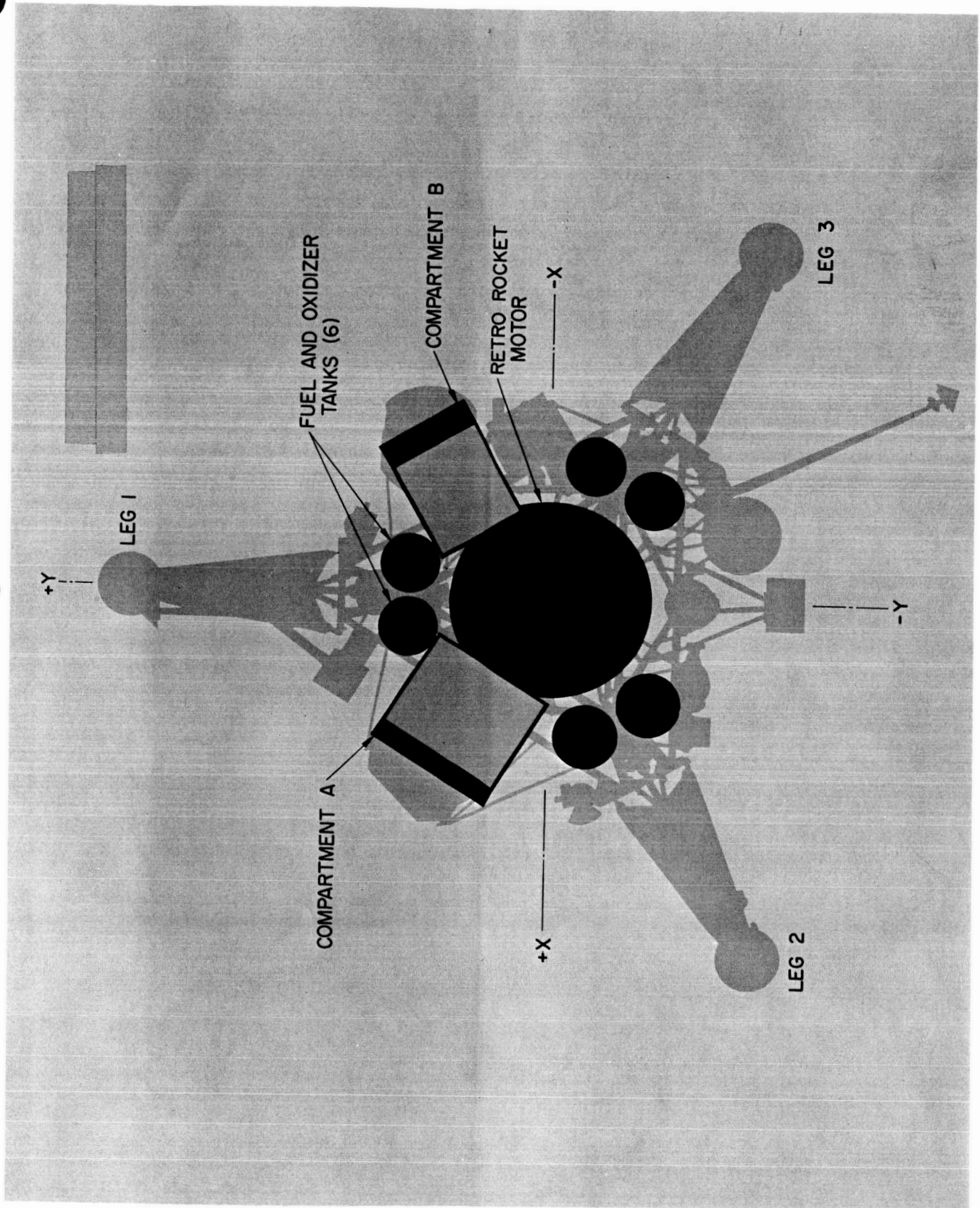
Figure 1. Passive control
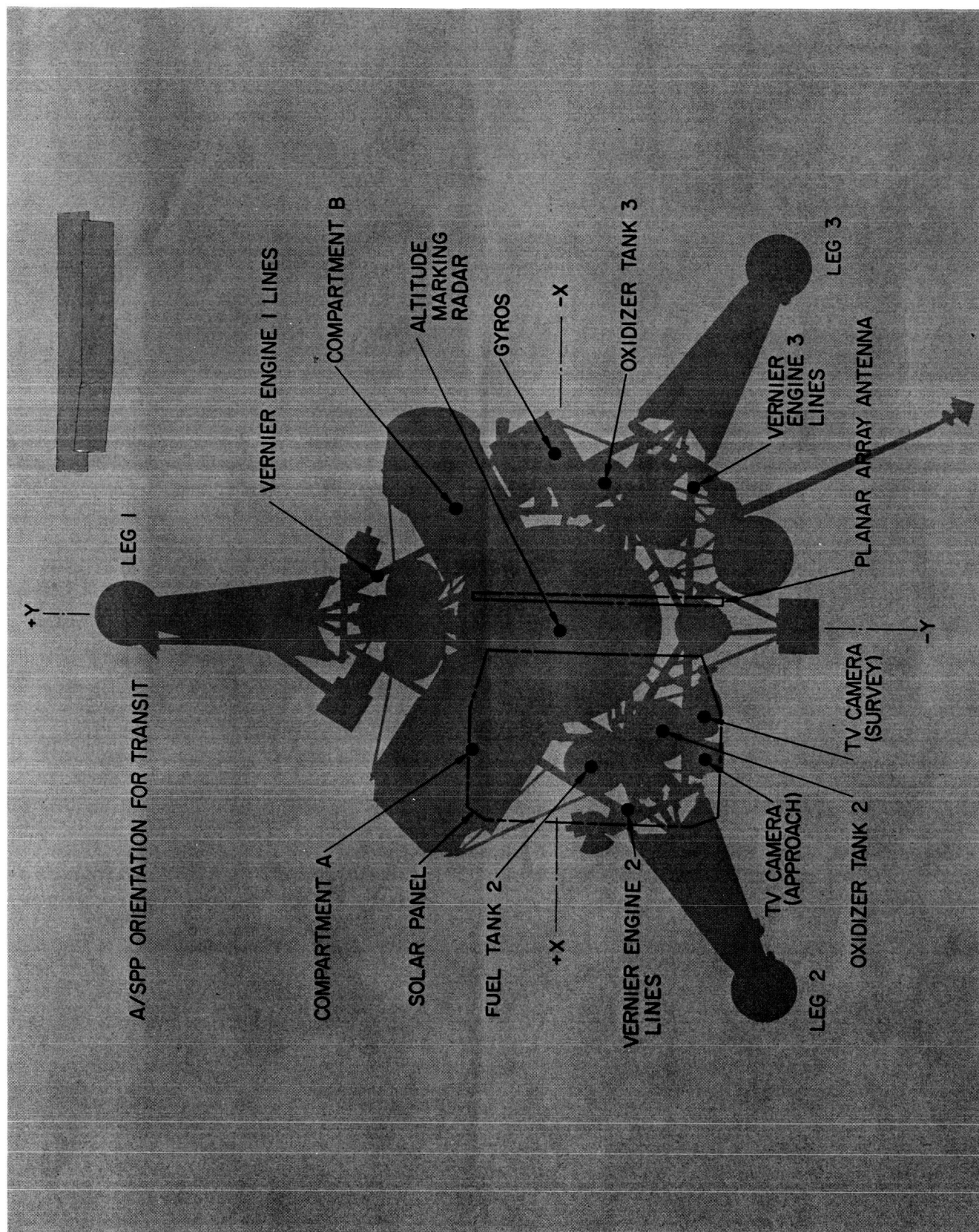
Figure 2.   Super insulation

Figure 3.   Active control

The following labels appear in the figure:

A/SPP ORIENTATION FOR TRANSIT
LEG I
+Y
VERNIER ENGINE I LINES
COMPARTMENT B
ALTITUDE MARKING RADAR
GYROS
-X
OXIDIZER TANK 3
VERNIER ENGINE 3 LINES
LEG 3
PLANAR ARRAY ANTENNA
-Y
TV CAMERA (SURVEY)
TV CAMERA (APPROACH)
OXIDIZER TANK 2
LEG 2
VERNIER ENGINE 2 LINES
+X
FUEL TANK 2
SOLAR PANEL
COMPARTMENT A

Semi-active control (Fig. 4) consisted of a number of temperature-actuated switches (nine in Compartment A and six in Compartment B). Each compartment, which was enclosed in a shell with an inner insulating blanket covering the bottom and four sides, contained a structural tray for mounting electronic equipment. The switches were attached to the top of the tray and they varied the thermal conductance between the tray and the outer radiating surfaces (back aluminized Vycor mirrors), thereby varying the heat dissipating capability of the compartments. When tray temperature increased, heat transfer across the switch increased. During the lunar night, the switches opened, decreasing conductance between the tray and the radiators to a very low value to conserve the heat. When heat dissipation from the electronic equipment was not sufficient to maintain required tray temperatures, even with the switches open, a heater on each tray supplied the necessary energy. All electronic equipment which had to operate both day and night, and whose temperature requirements could not be met by passive or active control, were mounted--together with the main battery--in one of the compartments. Examples of units controlled by active and semi-active means are shown in Table 1. All other units were passively controlled. Also shown in Fig. 4 is the Flight Control Sensor Group, which has the same type of radiators as those atop the compartments. In this case, however, they form part of a passive control system only, there being no temperature-actuated switches between them and the components which they are cooling.

Table 1. Use of active and semi-active thermal control

| Type of Control	Unit	Used During
Semi-Active and Active	Compartments A and B	Transit and Lunar Day (Semi-Active) Lunar Night (Semi-Active and Active)
Active	Flight Control Gyroscopes	Transit
	Altitude Marking Radar Electronics	Transit (unit jettisoned during terminal phase)
	Vernier Engine Propellant Lines	Transit
	Vernier Engine No. 2 Oxidizer and Fuel Tanks	Transit
	Vernier Engine No. 3 Oxidizer Tank	Transit
	Approach Television Camera	Transit (not used on Surveyor I)
	Survey Television Camera	Transit (might have been needed at dawn of second lunar day if communication had been established with the spacecraft)
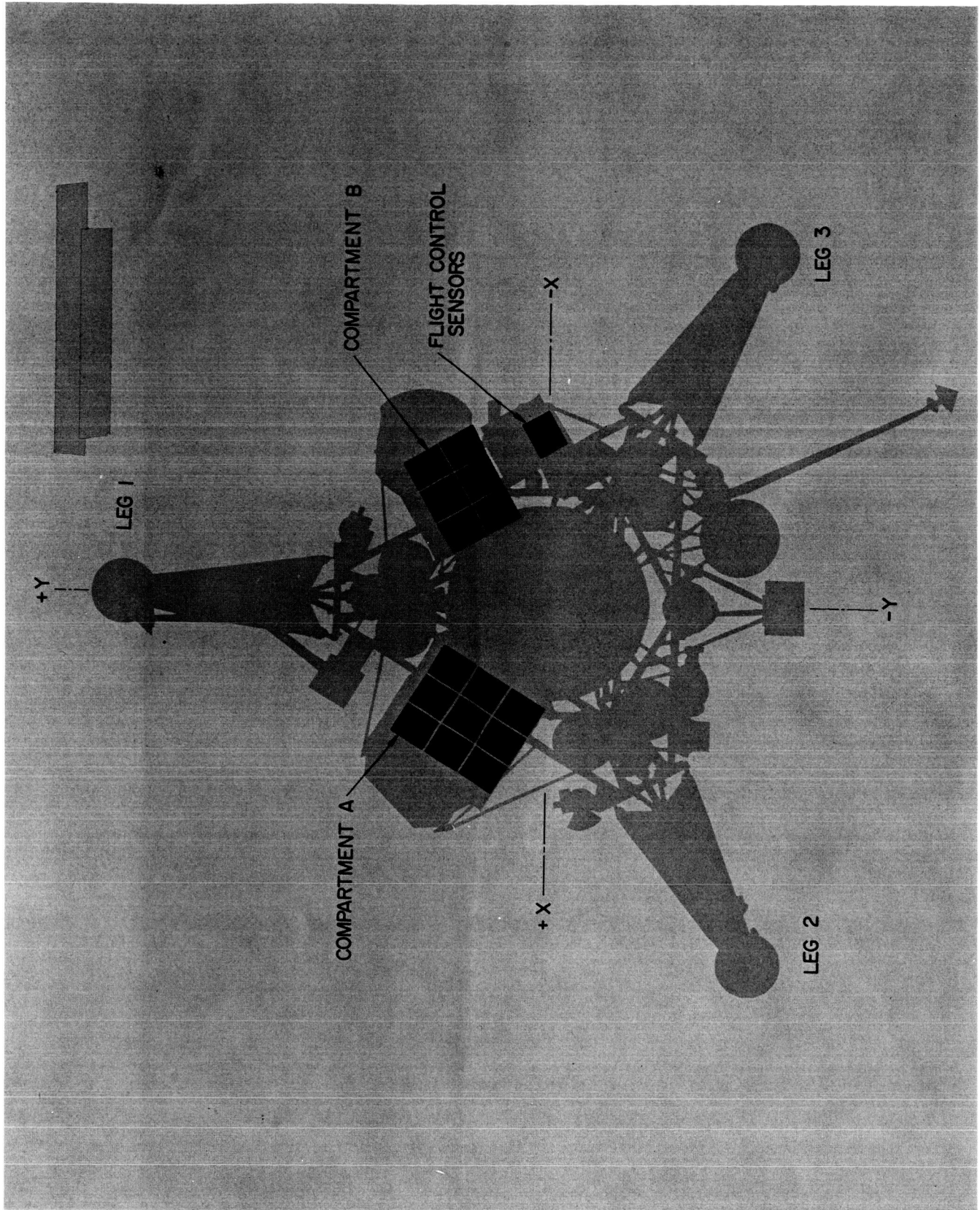
Figure 4. Semi-active control

In most cases, passively-controlled items reached their equilibrium conditions rapidly; thus, their radiative properties had only to be designed so that the unit remained within operating limits during the short time transients imposed by sun acquisition, midcourse, and terminal maneuvers. The main retro motor, however, could not be held at the correct equilibrium temperature throughout transit; and, for this reason, it was covered by an insulating blanket and preconditioned before flight. The preconditioning temperature was adjusted so that the solid fuel bulk temperature would fall to the correct temperature at the start of the terminal descent. The fuel and oxidizer tanks for the vernier engine system were also in a continuous transient during transit with the additional backup for the three shaded tanks of active control which could be used, under thermostatic control, during the later stages of the flight.

GENERAL FLIGHT PERFORMANCE AND PROBLEM AREAS

The general flight performance of Surveyor I has been described as "better than nominal." This remark also applies to the thermal performance of the spacecraft. Figs. 5 and 6 show the prediction ranges and the flight results for certain representative items from the 78 thermal sensors (72 were used on the lunar surface, since three were attached to the Altitude Marking Radar which was jettisoned at the start of retro burn, and three were attached to the main retro motor which was jettisoned after retro burn). Only one sensor fell far from its predicted value--that for the main retro nozzle, and this actually behaved as it did in ground test. Apparently, allowances made in the flight prediction of this item, which allowed for back radiation from the chamber floor, may have been cancelled by reflection from other parts of the spacecraft, or the joint conductance between the nozzle and the retro motor may have been different in the ground test (inert) model from the flight motor.

The only problem area in flight was the behavior of the Auxiliary Battery, which ran cooler than predicted and approached its lower temperature limit. Switching it into the system a little earlier than called for in the flight plan brought this battery up to operating temperature before the terminal maneuver, and it performed to specification.

GENERAL LUNAR PERFORMANCE AND PROBLEM AREAS

Very few predictions were made for the performance of Surveyor I on the lunar surface since the primary objective of Mission A was to demonstrate flight performance, landing capability, and picture-taking potential--rather than survival on the surface and continuous picture-taking, which actually occurred. For this reason, the predictions which had been made were quite general and frequently directed only at potentially catastrophic failure modes--such as rupture of the vernier engine fuel and oxidizer tanks, failure of the vernier engine control valves, or overheating of the compartments and survey television camera during lunar noon. Therefore, there was no "nominal" data for comparison with actual performance. Results obtained for three items of interest (shown in Figs. 7, 8, and 9) indicate reasonable values for temperature even under extreme lunar environmental conditions. Temperatures encountered by the vernier engines were high and caused some alarm, since propellant valve failure had occurred in ground test after long exposure to these temperatures. However, results for the second lunar day confirm that such a failure did not occur.
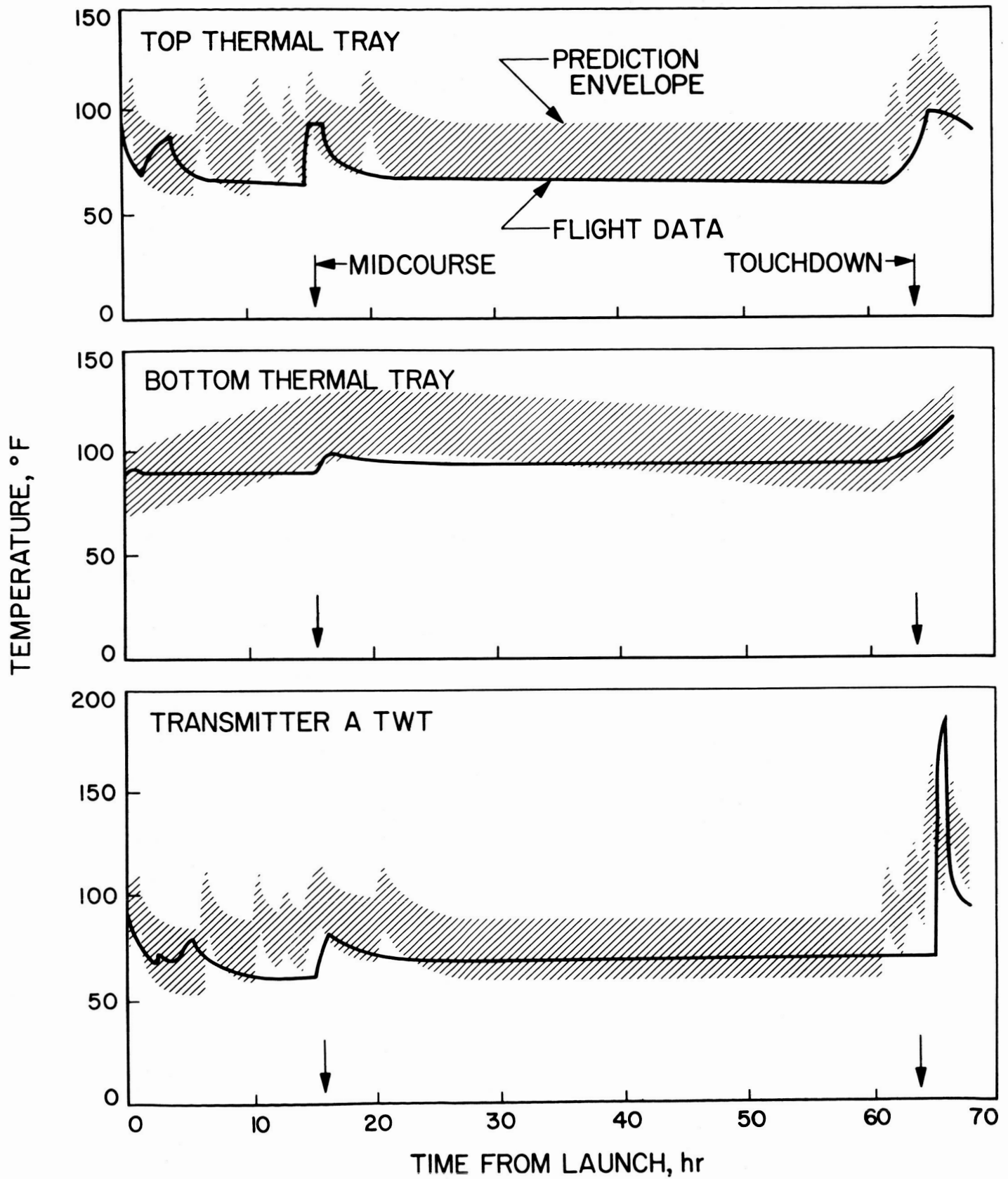
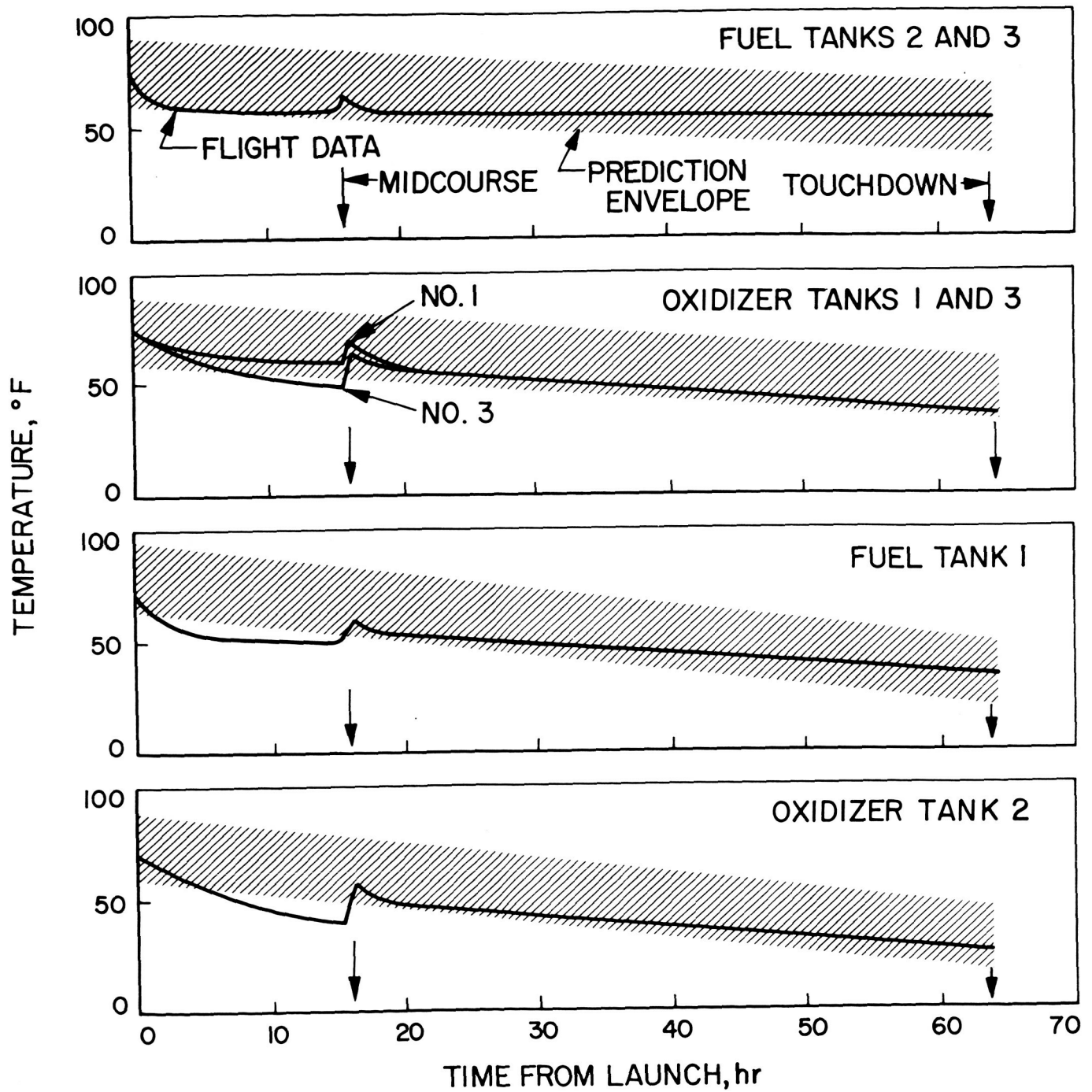Figure 5. Prediction ranges and flight results

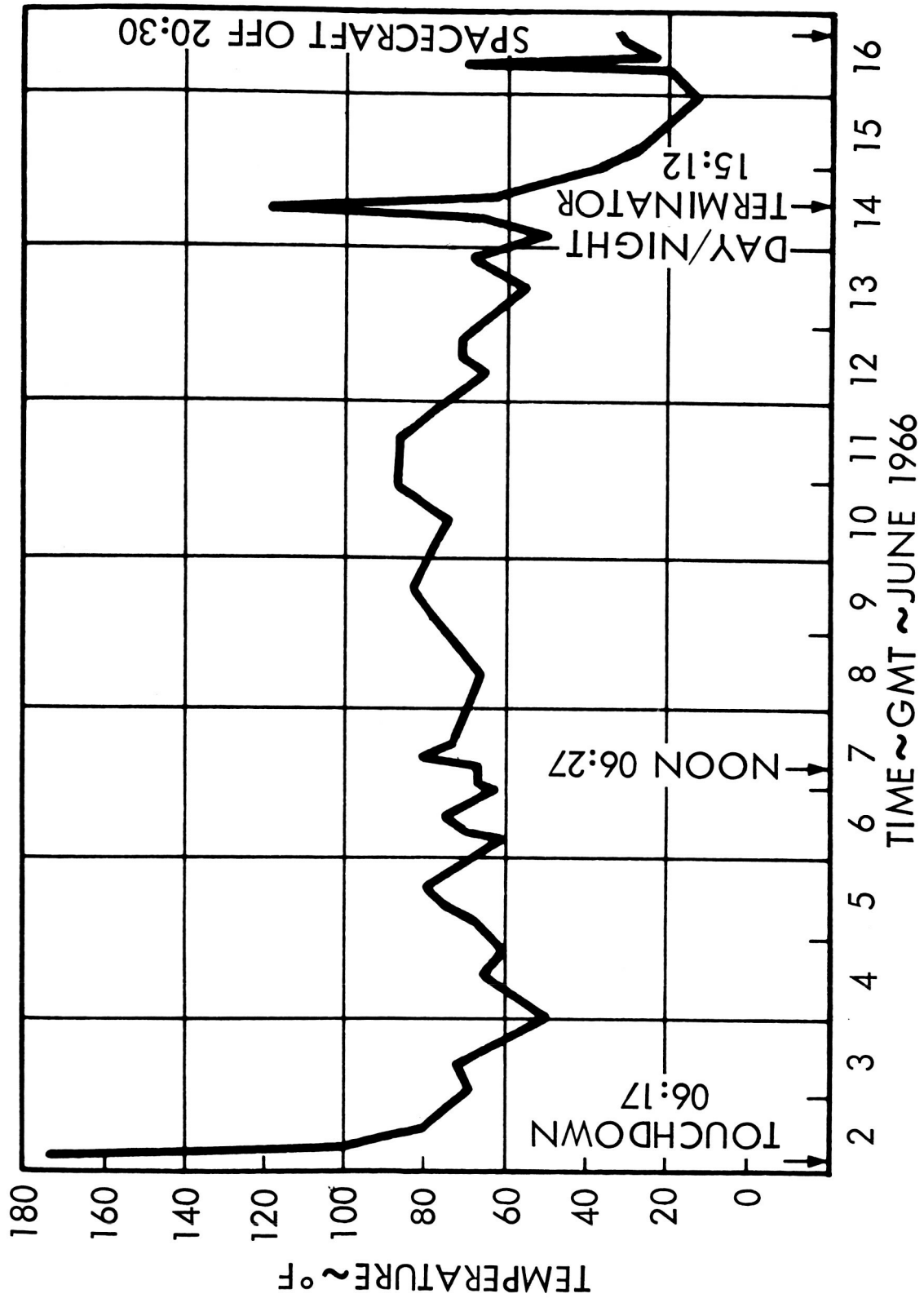Figure 6. Prediction ranges and flight results

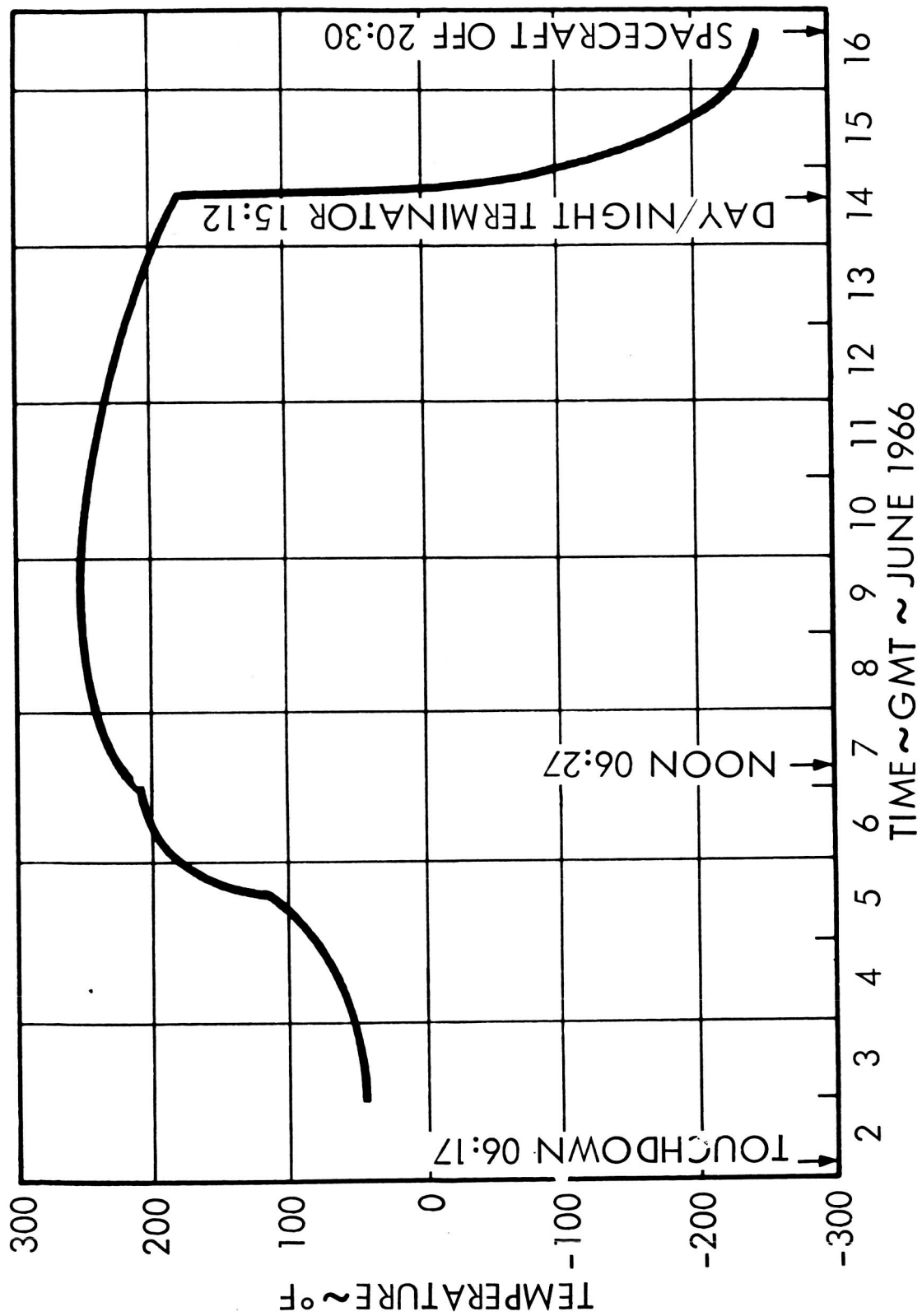Figure 7. Transmitter A temperatures
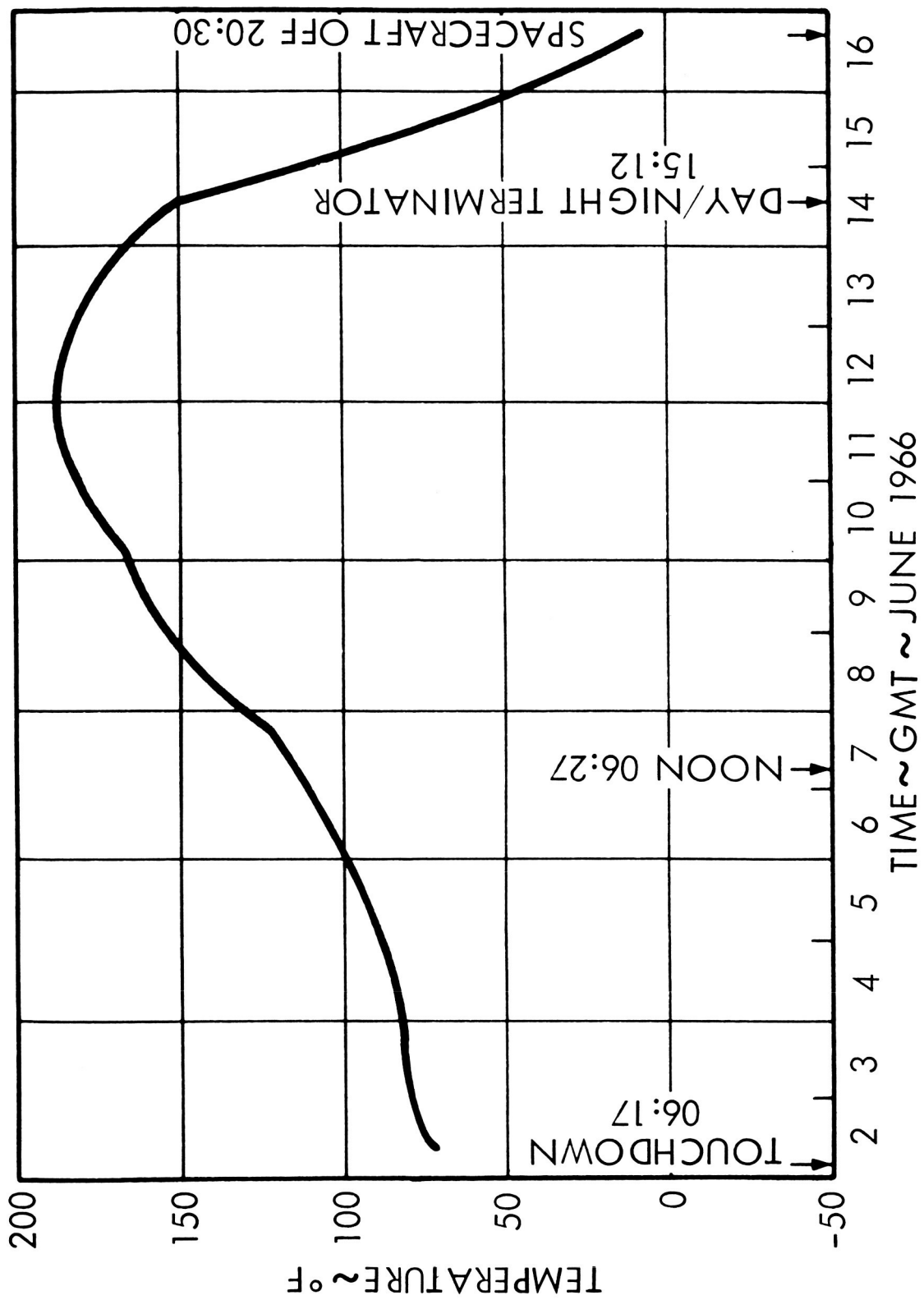
Figure 8. Vernier Engine No. 1 temperatures

Figure 9. Fuel Tank No. 1 temperature

The only problem area on the lunar surface occurred toward the end of the first lunar day (Fig. 10) when certain temperature-controlled switches in Compartments A and B were stuck in the closed position. This problem had been known from ground test. In the circumstances, heat losses from the compartments would be higher than could be tolerated during the lunar night if spacecraft interrogation was to be continued. As can be seen from Fig. 10, one of the switches (which was not instrumented) opened very early in the lunar night (this was confirmed by other data obtained from the spacecraft); the other switch in Compartment A opened a little later; and the behavior of Compartment A indicated that all of its switches were open. The thermal behavior of Compartment B indicated, however, that probably three of its temperature-actuated switches were still closed at the time that all communication with the spacecraft was discontinued to save battery power. When communication was re-established on the second lunar day, temperatures were up so that all thermal switches would be normally in closed. However, preliminary engineering evaluation indicates a high probability that all switches opened at some time during the lunar night.

EXPERIMENTS CARRIED OUT AND ATTEMPTED ON THE LUNAR SURFACE

Several engineering experiments were carried out while Surveyor I was communicating data from the moon. These are described in following paragraphs.

Lunar Surface Temperatures from Readings on Isolated Sensors

H. Knudson of Hughes Aircraft Company suggested that it should be possible to deduce effective radiating temperatures of the lunar surface from measurements taken by sensors on the outer surfaces of Compartments A and B. These were on thin material, reasonably well isolated from the rest of the spacecraft, and their equilibrium temperature was dependent to a large extent on the lunar surface temperature. Preliminary calculations reported in the "Five-Day Report," Project Document No. 97, indicate that the lunar surface brightness temperature was 165°F at 1200 GMT on 2 June 1966. This can be compared with the temperature predicted from earth-based data of 120°F for that area and time. More detailed results, later obtained by the Thermal Properties Working Group, are reported in a "Thirty-Day Report" to be released shortly.

Spacecraft Shading

As the first lunar noon was approaching, it was elected to re-position the Solar Panel and Planar Array to cast a shadow on the TV Camera and compartments. This maneuver, while reducing the output of the Solar Panel, provided a more desirable thermal environment for the compartments and camera, and permitted picture-taking even during the lunar noon.

Compartment Heat Losses

It had been hoped that, with the onset of the lunar night, it would be possible to deduce the heat losses from the compartments by commanding a suitable heater and receiver/transmitter cycle on the spacecraft. This experiment was largely nullified by the sticking of the temperature actuated switches in Compartment B, the initial sticking of the switches in Compartment A, and uncertainties in the heat dissipation of the battery.
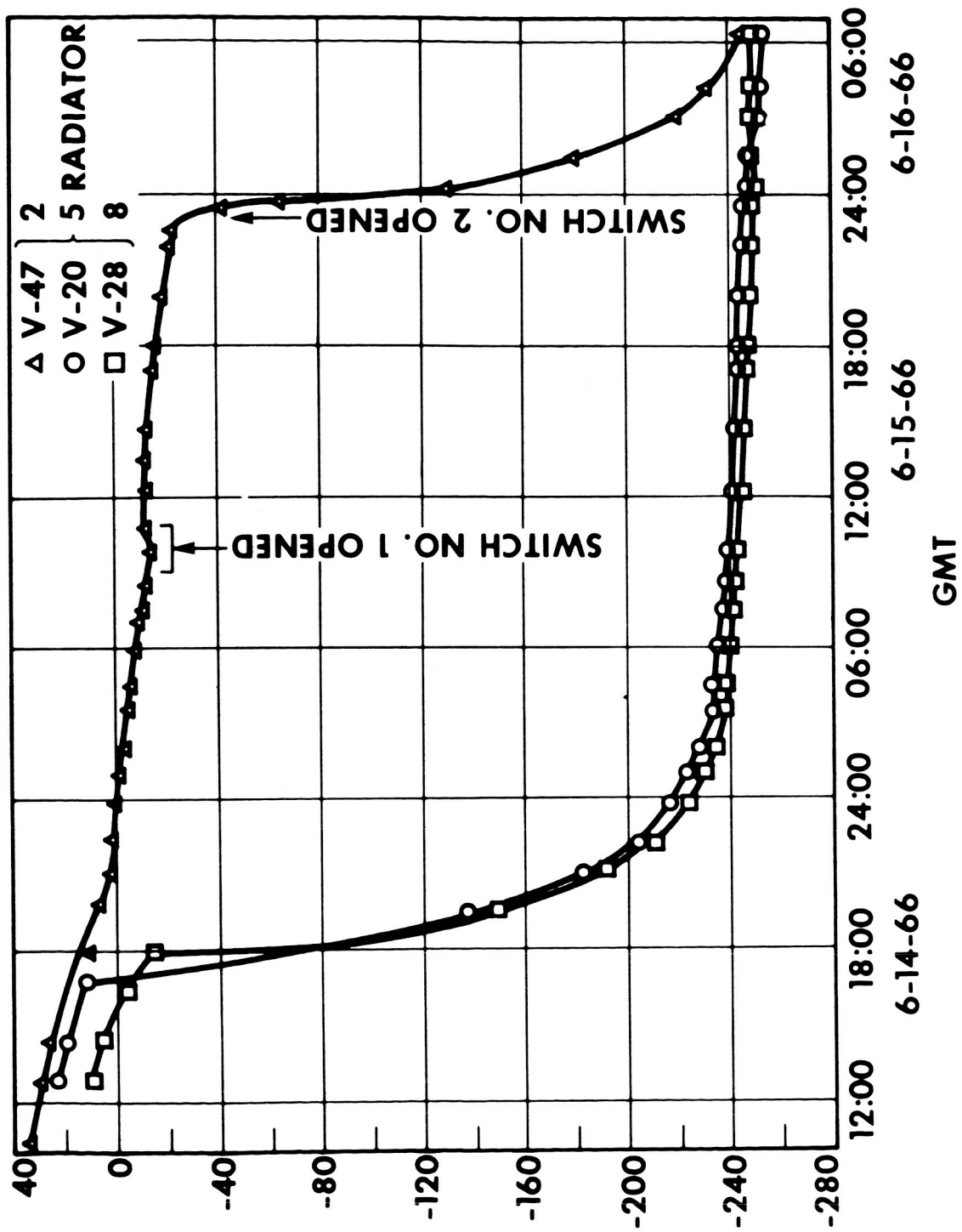
Figure 10. Compartment A externals

Prediction of Vernier Engine Propellant Temperatures for Second Lunar Day

It was hoped that, during the second lunar day, it would be possible to fire the Vernier Engines and examine the lunar surface in the vicinity of Engine No. 3 before and after the firing to determine erosion effects from a low-thrust firing. Since the helium had been dumped immediately after landing, the only pressure available was the vapor pressure for oxidizer feed. Therefore, it was important to know the probable temperature of the oxidizer tanks.

Predictions were made (from data obtained during the first lunar day and the first 48 hours of the lunar night) for the second lunar day. These predictions could not be checked with great accuracy, since Surveyor I did not produce data until just before noon on the second lunar day. Certain facts did emerge, however. First, just before the second lunar noon, all fuel tanks were cooler than at the equivalent time in the first lunar day. This was to be expected since they froze during the lunar night, and initial conditions for the second day transient were very different from those of the first day. As the lunar day progressed, fuel tank temperatures approached--but did not reach--the temperatures attained at equivalent times in the first lunar day. The oxidizer tanks, on the other hand, were between 20°F and 40°F hotter on the second lunar day, when the spacecraft was first picked up, than on the first lunar day. This was contrary to prediction, but is thought to be due to venting of the oxidizer tank pressure which occurred before noon of the first lunar day. This venting and loss of latent heat of vaporization of the oxidizer gave a false heating curve during the first first lunar day. Toward the end of the life of the spacecraft, temperatures of the oxidizer tanks fell and became almost identical with results noted for the first lunar day. In the final event, it was not possible to fire the vernier engines for reasons other than thermal control.

Particles on Radiating Surfaces

Narrow-angle pictures, taken toward the end of the first lunar day of the top of Compartment A, showed a number of particles on top of the Vycor glass mirrors (Fig. 11). Examination of earlier photographs (Fig. 12) indicates that these particles were present on the radiators very soon after landing. Some preliminary experiments have been made using sand, fine grit, and lint on a similar radiator, taking pictures at equivalent distances with similar lighting on earth. These pictures indicate that the particles appearing in the Surveyor I photographs are probably of the consistancy of coarse sand. Therefore, they are probably part of the lunar surface material thrown up during the touchdown of the spacecraft, possibly by vernier engine exhaust.

Self-Diagnosis - Broken Radiator

During the second lunar day, a survey was run over the top of Compartment A to look for further dirt accumulation (Fig. 13). When compared with Fig. 12, it can be seen that some damage to a radiator has occurred. A narrow-angle picture (Fig. 14) shows that a sector of one radiator had shattered. This was not sufficient to result in higher compartment temperatures, but was an interesting example of self-diagnosis by a spacecraft.
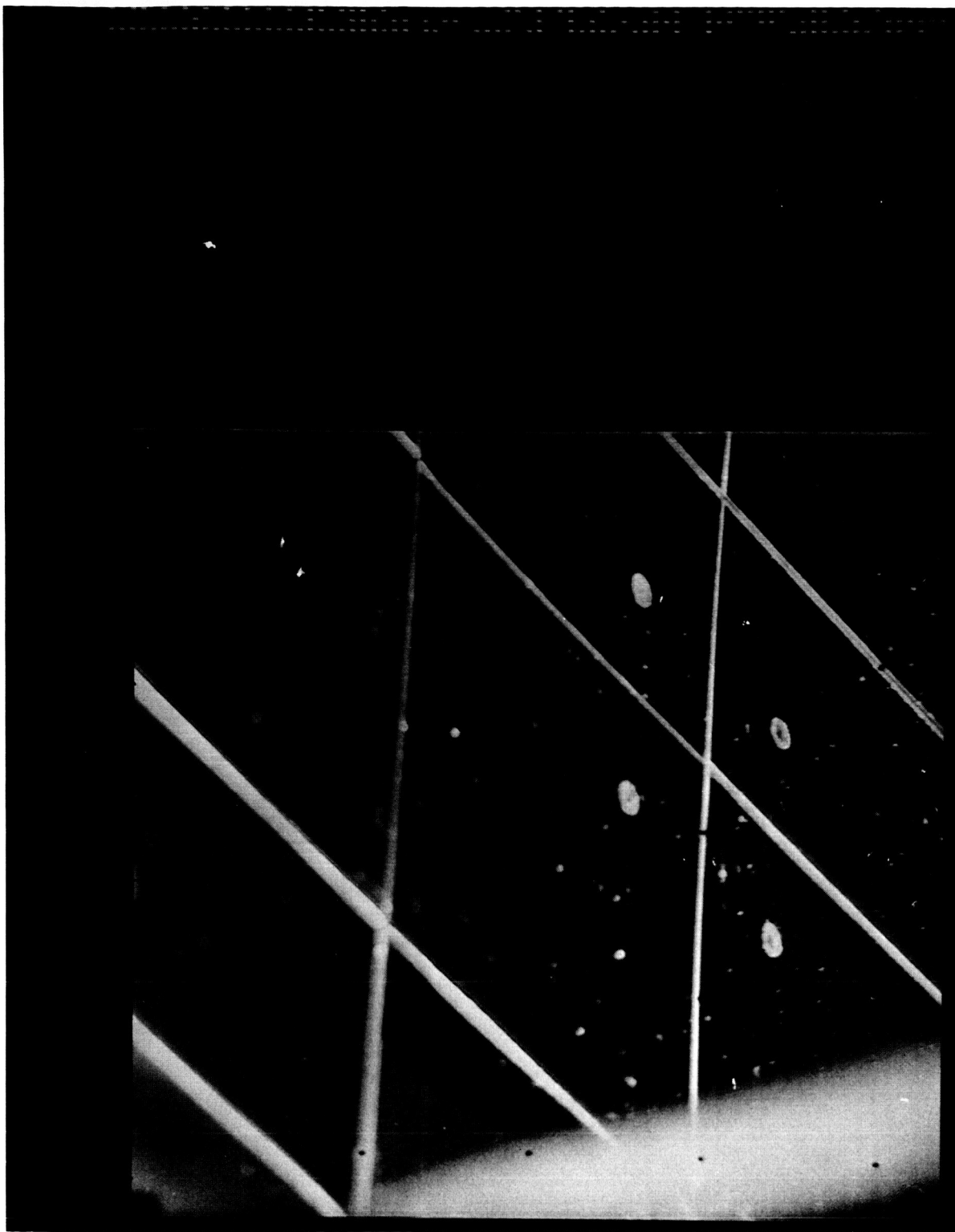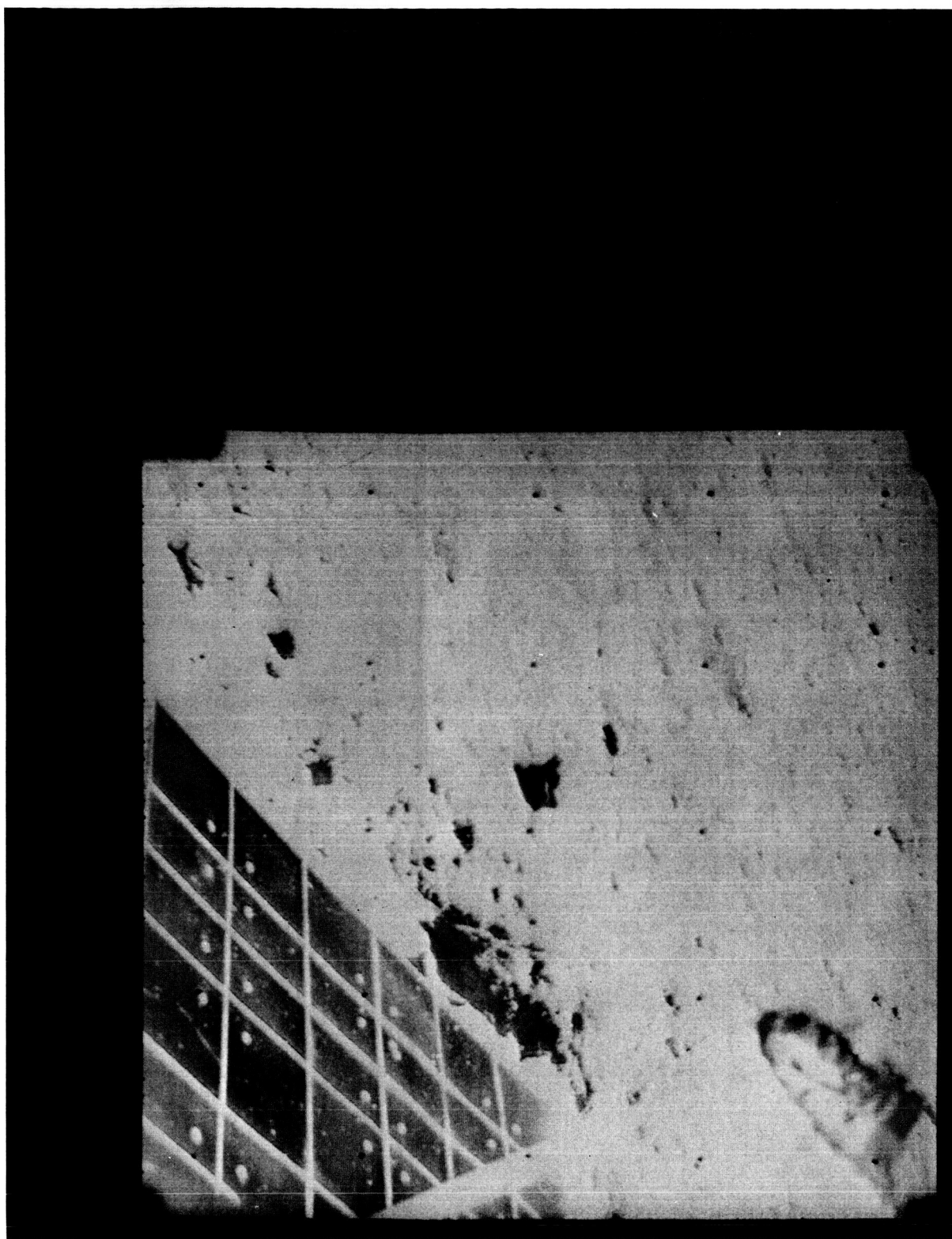
Figure 11. Particles on Compartment A

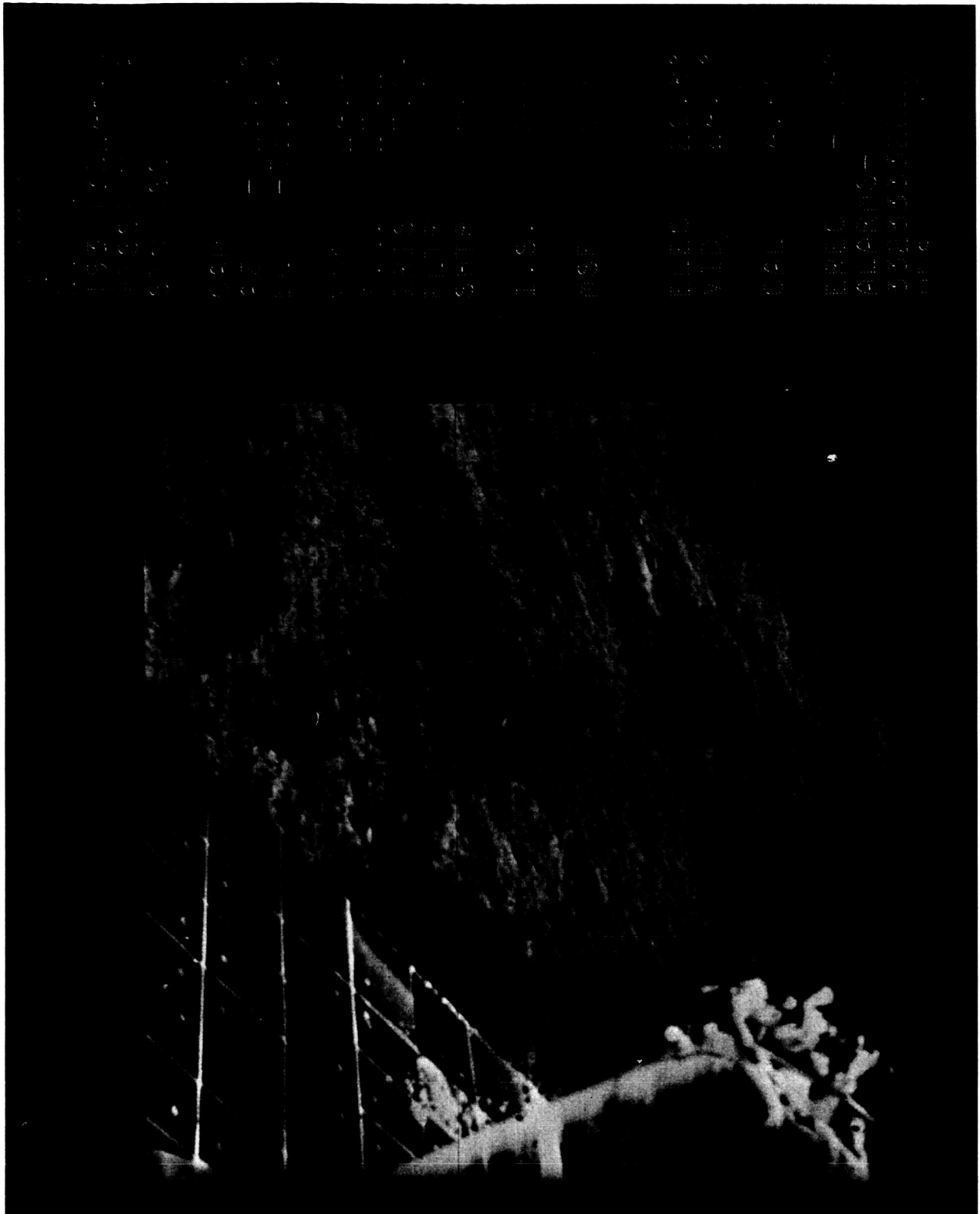Figure 12.   Early picture of Compartment A particles
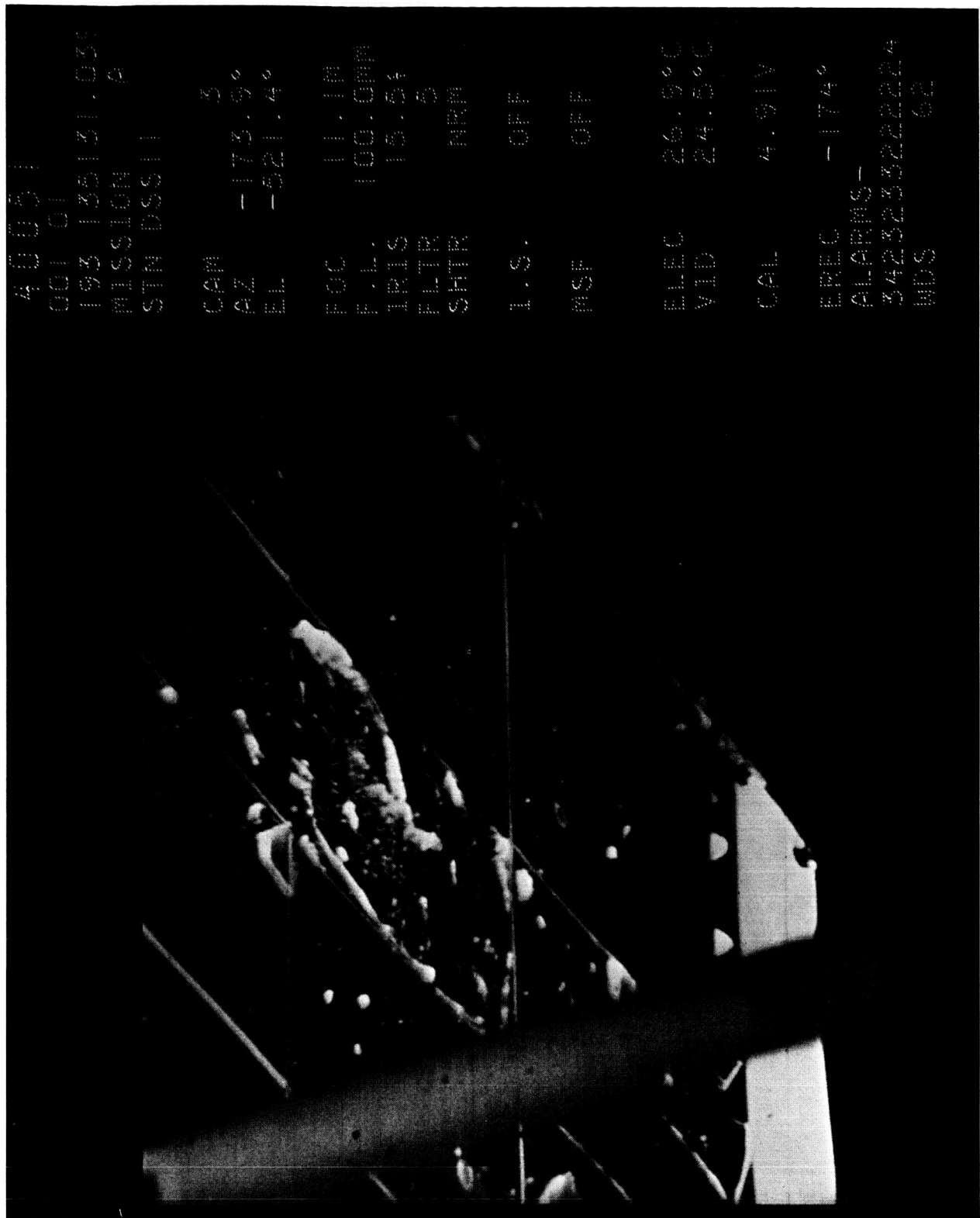
Figure 13.   Compartment A during second lunar day

Figure 14.   Shattered radiator view

CONCLUSION

The flight and lunar surface performance of Surveyor I was excellent and exceeded all expectations. Certain engineering experiments were attempted with varying degrees of success. These gave a great deal of information and indications of further experiments which should be undertaken.